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THE OFFICE OF EXPLORATION

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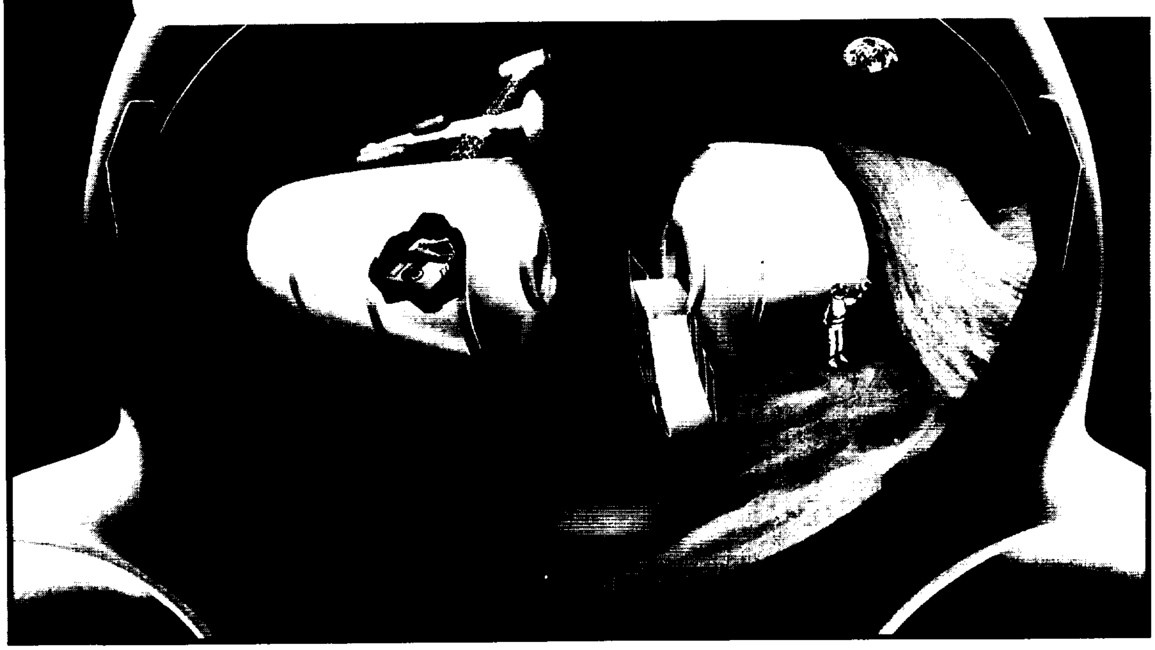

EXPLORATION STUDIES TECHNICAL REPORT

Volume V: Technology Assessment

National Aeronautics and
Space Administration

This publication is one of seven documents describing work performed in fiscal year 1989 under the auspices of the Office of Exploration. Volume 0, titled "Journey Into Tomorrow," provides an overall programmatic view of the goals, opportunities, and challenges of achieving a national goal for human exploration. The technical details and analyses are described in the other six volumes of the series. Volume I is Mission and Integrated Systems; Volume II is Space Transportation Systems; Volume III is Planetary Surface Systems; Volume IV is Nodes and Space Station Freedom Accommodations; Volume V is Technology Assessment; and Volume VI is Special Reports, Studies, and In-Depth Systems Assessment. These seven volumes document the status of Exploration Technical Studies at the conclusion of the FY 1989 study process in August 1989, and, therefore, do not contain any analyses, data, or results from the NASA 90-Day Study on Human Exploration of the Moon and Mars.

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The Office of Exploration FY 1989 Annual Report

Exploration Studies Technical Report Volume V: Technology Assessment

NASA

Disclaimer Statement

The Exploration Studies Process, as explained in detail in Section 2 of Volume I, was a requirements driven, iterative, and dynamic process developed for case study analysis. This process consisted of three parts: (1) requirements generation, (2) implementation development, and (3) integrated case study synthesis.

During the final step of the process, an integrated mission was developed for each of the case studies by synthesizing the implementations developed earlier into a coherent and consistent reference mission. These are presented in Section 3 of Volume I of this annual report. Given the iterative and dynamic nature of this process, there are two important items to note:

- **The integrated case studies do not always reflect a mission that has a direct one-to-one correspondence to the requirements specified in the March 3, 1989, *Study Requirements Document*. Many changes were made to these requirements prior to and during the synthesis activities when warranted.**

- **The integrated case studies presented in Volume I represent the results of the synthesis process. Volumes II, III, and IV are the implementation databases from which the integrated case studies were derived. Therefore, the implementations outlined in Volumes II, III, and IV are generally reflected in the integrated case studies, but, in some cases, the implementations were changed in order to be effectively included in the integrated case studies. These modifications are only briefly discussed in Volumes II, III, and IV.**

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1 General

1.1 Overview

Significant progress has been made in both the maturity and depth of understanding of the technology needs since the Interim Technology Assessment, dated March 15, 1989, was distributed. The primary intent of this document is to provide the basis for developing the scope and strategy for the space technology program; that is, guide the technology programs of the Office of Aeronautics and Space Technology (OAST). This document is organized as follows: Section 1, in addition to this overview, describes the approach used for defining technology requirements. Section 2 is a summary of technology needs (this section also ranks technology needs and assesses the availability). Section 3 summarizes the technology program. This summary focuses on the Pathfinder and Civil Space Technology Initiative (CSTI) element programs. Section 4 provides recommendations. Section 5 contains acknowledgements.

1.2 Technology Requirements Approach

1.2.1 Purpose

This section provides the FY89 assessment of technology needs for human exploration of the solar system and is an update to the FY89 Interim Technology Assessment dated March 15, 1989.

1.2.2 Technology Needs Database (TNDB)

The data provided in this document represents the best estimate on cumulative results of FY88 and FY89 studies and summarized information derived from the Technology Needs Database (TNDB). The TNDB is an electronic database repository which contains the current information on each technology. The TNDB will be published as a separate document and will be updated periodically as new technology data becomes available.

1.2.3 Methodology and Ground Rules

The determination of technology needs at any point in time is based on the cumulative effort of ongoing Office of Exploration (OEXP) studies. While the technology needs are largely driven by case study results, data from trade, parametric, and special assessment studies are also taken into consideration. Thus, all results of the case studies conducted to date have been used in the generation of technology needs. For this particular evaluation, the technology needs are driven mostly by the FY89 studies with FY88 study results included in the database. The information contained in this database are based on conceptual designs and trade studies performed by integration agents (IA's) and special assessment agents (SAA's).

Each technology need has been documented as specifically as possible. During early phases of analysis it was appropriate to group potentially relevant technology needs under one entry in the database. Once there was sufficient data to support detailed appraisal and comparison of alternate technologies they were tracked separately and documented accordingly. The technology agent for each IA was responsible for integrating the data from all available sources (other IA's, SAA's, etc.) to establish the technology needs for his technical area. The SAA's coordinated their data and technical concerns with the appropriate IA. Exploration Technology Working Group (ExTWG) meetings served as a forum to discuss issues and support the ranking prioritization process.

Technology needs which were not supported by a benefit statement are not included in this document. This benefit statement, to the extent possible, includes quantification of the benefit (e.g., mass saved, reliability increased) and is supported by graphical and/or textual data.

1.2.4 Prioritization Criteria

Determining the criteria for the prioritization of technologies was one of the more difficult tasks that was accomplished during the study period. Drawing upon approaches developed by OAST, the ExTWG formulated the following approach for prioritizing the technologies. The criteria defining the technologies that were studied are a function of (1) the category (benefit) of the need; (2) the timing of the need; and (3) the challenge (risk) perceived to perform the technology development as shown in table 1.2.4-I.

Preliminary technology ranking was accomplished by the technology agents for each IA based on needs within his area. The first step in the integration process was performed on technologies from all sources that the IA needed to perform his specific mission. The next step in the integration process was to have the ExTWG make a recommendation on a ranking of the technology needs and list issues that could not be resolved by the ExTWG. Mission Analysis and Systems Engineering (MASE) then adjusted the technology needs ranking to reflect the relative benefits from an overall mission perspective. This formed the basis of the MASE recommendation to the OEXP Director of Technology. The final ranking in this report was recommended by the OEXP Director of Technology and approved by the OEXP Assistant Administrator.

TABLE 1.2.4-I EXPLORATION RESEARCH AND TECHNOLOGY RANKING CRITERIA

	System/Approach	Common	Unique
Need Categories	Enabling	I	II
	Enhancing	III	IV

	Period	Phase C/D	IOC
Needs Timing	A Near Term	Post 1994	Pre 2004
	B Mid Term	Post 1997	Pre 2007
	C Far Term	Post 2000	Pre 2010

Development Risk/Challenge	1 High Risk	Fundamental R&D and/or no program in place
	2 Med Risk	Components and/or program in place with limited funding
	3 Low Risk	On schedule; Program fully funded

Definitions:

Common — required by all or most pathways and approaches. Specifically, a technology must be needed for both lunar and Mars scenarios in order to be in this category.

Unique — required by only one or two pathways or approaches that we, as an agency, wish to protect the option for implementing

Enabling — those technologies which must be available in order for the mission to be a success either from a technical feasibility/performance aspect or from an affordability aspect

Enhancing — those technologies which yield a significant net positive benefit in terms of capability and/or affordability

The technology needs have been ranked according to the criteria defined in table 1.2.4-I. While there is some grey area in the middle of the priority order, in general the combinations of need category and timing yield the order of priority shown in table 1.2.4-II. Within each category/timing priority group, those technologies with the highest risk are assigned the highest priority. Clearly, those technologies which are enabling, needed in the initial phase of exploration, and are of the greatest challenge (risk) to develop are of top priority.

TABLE 1.2.4-II PRIORITIZATION OF TECHNOLOGY NEEDS

IA	Common, Enabling, Near Term
IIA	Unique, Enabling, Near Term
IB/IIIA	Common: Enabling, Mid Term & Enhancing, Near Term
IIB/IVA	Unique: Enabling, Mid Term & Enhancing, Near Term
IIIB	Common, Enhancing, Mid Term
IVB	Unique, Enhancing, Mid Term
IC	Common, Enabling, Far Term
IIC	Unique, Enabling, Far Term
IIIC	Common, Enhancing, Far Term
IVC	Unique, Enhancing, Far Term

2 Summary of Technology Needs

2.1 Ranking of Technology Needs

The technology needs have been ranked according to the criteria presented in section 1.3 with regards to need category (benefit), timing, and development challenge (risk). Clearly, those technologies which are enabling, needed in the initial phase of exploration, and are the greatest challenge to develop are of top priority. Table 2.1-I presents a listing of technology needs sorted by priority. A discussion of each technology is provided in the appropriate Integration Area (IA) in the TNDB.

One area lacking adequate definition at this time is the technology needs for science or "user" payloads and systems. We anticipate that some of the instrumentation that will be used to take advantage of opportunities in human exploration missions will require technology development. We cannot identify these technology development needs at present, but will work with the Office of Space Science and Applications (OSSA) to determine the appropriate technology areas and required timeframes.

TABLE 2.1-I TECHNOLOGY NEEDS BY RANK

Technology	Ranking			Functional Area	Integration Area
Construction technology	I	A	2	CONSTRUCTION	PSS
Surface Transportation Technology	I	A	2	CONSTRUCTION	PSS
RLSS Supporting Technologies	I	A	2	LSS	PSS
Trace Contaminant Control	I	A	2	LSS	PSS
Waste Management	I	A	2	LSS	PSS
Water Recovery/Management	I	A	2	LSS	PSS
In-Space Vehicle Processing/Servicing	I	A	2	In-Space Ops	NODE
Aerocapture (Low Energy @ Earth)	I	A	2	AEROCAPTURE	TRANS
Radiation Protection	I	A	2	Human Systems	TRANS
Surface Power (< 1 MWe)	I	A	3	ENERGY	PSS
EVA Systems Technology	I	A	3	Human Systems	PSS
Atmosphere Revitalization	I	A	3	LSS	PSS
Cryo Fluid Supply/Storage/Management	I	A	3	CRYO FLUID MGT	NODE
Cryo Fluid Transfer/Handling	I	A	3	CRYO FLUID MGT	NODE
Chemical Ascent/Descent Engine	I	A	3	A/D CHEM PROP	TRANS
Cryo Fluid Supply/Storage/Management	I	A	3	CRYO FLUID MGT	TRANS
Cryo Fluid Transfer	I	A	3	CRYO FLUID MGT	TRANS
Long-Lived Life Support Units	I	A	3	LSS	TRANS
Advanced Chemical Transfer Engines	I	A	3	STV CHEM PROP	TRANS

Technology	Ranking			Functional Area	Integration Area
In-Space Assembly - Vehicle Level	II	A	2	In-Space Ops	NODE
Aerocapture (Low Energy @ Mars)	II	A	2	AEROCAPTURE	TRANS
Aero Entry/Landing @ Mars	II	A	2	ENTRY SYSTEMS	TRANS
Nuclear Thermal Rocket Propulsion	II	A	3	STV NTR PROP	TRANS
Autonomous Rendezvous and Docking	III	A	1	In-Space Ops	NODE
Mobile Power Systems	III	A	2	ENERGY	PSS
Thermal Control	III	A	2	ENERGY	PSS
In-Space Assembly - Element Level	III	A	2	In-Space Ops	NODE
Autonomous Landing	III	A	2	ENTRY SYSTEMS	TRANS
Dust Contamination Control	III	A	3	Human Systems	PSS
Information Management	III	A	3	COMMUNICATION	TRANS
Ka-Band Communications Technology	III	A	3	COMMUNICATION	TRANS
Lunar Oxygen Production	II	B	2	ISRU	PSS
Mining Technology	II	B	2	ISRU	PSS
Mars Water Extraction	II	B	2	ISRU	PSS
Mineral Beneficiation	II	B	3	ISRU	PSS
Aerocapture (High Energy @ Earth)	IV	A	2	AEROCAPTURE	TRANS
Artificial Gravity Vehicle	IV	A	2	ARTIFICIAL-G SYS	TRANS
Direct Entry @ Earth (High Energy)	IV	A	2	ENTRY SYSTEMS	TRANS
Artificial-g Vehicle Deployment and Control	IV	A	3	ARTIFICIAL-G SYS	TRANS
Tethers	IV	A	3	ARTIFICIAL-G SYS	TRANS
Parachute System (Earth/Mars)	IV	A	3	ENTRY SYSTEMS	TRANS
Inflatable Structures	III	B	2	CONSTRUCTION	PSS
Propellant Storage and Transfer	III	B	2	LAUNCH & LAND	PSS
Surface Power (> 1 MWe)	I	C	2	ENERGY	PSS
Food Production	III	C	2	LSS	PSS
Essential Element Extraction	III	C	2	ISRU	PSS
High Power Electric Propulsion (MW class)	III	C	2	STV ELEC PROP	TRANS
Nuclear Power for NEP	III	C	2	STV ELEC PROP	TRANS

Technology	Ranking			Functional Area	Integration Area
Aerocapture (Dual use @ Mars/Earth)	IV	C	1	AEROCAPTURE	TRANS
Lunar Ceramics Production	IV	C	2	ISRU	PSS
Lunar Hydrogen Production	IV	C	2	ISRU	PSS
Lunar Metals Production	IV	C	2	ISRU	PSS
Mars Atmospheric Oxygen Extraction	IV	C	2	ISRU	PSS
Phobos/Deimos Water Extraction	IV	C	2	ISRU	PSS
In situ Propellant Engines	IV	C	2	STV CHEM PROP	TRANS
Solar Power for SEP (MW class)	IV	C	2	STV ELEC PROP	TRANS

Ranking Key:

Need Category	I	Common, Enabling
	II	Unique, Enabling
	III	Common, Enhancing
	IV	Unique, Enhancing
Needs Timing	A	Near Term
	B	Mid Term
	C	Far Term
Development Risk	1	High Risk
	2	Med Risk
	3	Low Risk

2.2 Crosscutting Technology Areas

A crosscutting technology is defined as a technology which cuts across two or more technology areas of interest to the space exploration program. Application of a crosscutting technology to other exploration technology areas enhances performance and reliability. Thus, crosscutting technologies are critical to overall mission success. The crosscutting technologies include automation; robotics; maintainability; operability; and fault detection, isolation, and recovery (FDIR). Tables 2.2-I to 2.2-III provide an overview of the relationship of these crosscutting technologies to the technology areas of interest to the space exploration program. The crosscutting technologies are considered to be an integral part of all other technology areas and should be applied wherever necessary to assure adequate performance.

TABLE 2.2-I CROSSCUTTING TECHNOLOGIES - PLANETARY SURFACE SYSTEMS

Technology	Automation	Robotics	Maintainability	Operability	FDIR
Construction technology	•	•	•	•	•
Surface Transportation Technology	•	•	•	•	•
Inflatable Structures			•		•
Surface Power (< 1 MWe)	•		•	•	•
Mobile Power Systems	•	•	•	•	•
Thermal Control	•		•	•	•
Surface Power (> 1 MWe)	•		•	•	•
EVA Systems Technology	•	•	•	•	•
Dust Contamination Control	•	•	•	•	•
Lunar Oxygen Production	•	•	•	•	•
Mining Technology	•	•	•	•	•
Mars Water Extraction	•	•	•	•	•
Mineral Beneficiation	•	•	•	•	•
Essential Element Extraction	•	•	•	•	•
Lunar Ceramics Production	•	•	•	•	•
Lunar Hydrogen Production	•	•	•	•	•
Lunar Metals Production	•	•	•	•	•
Mars Atmospheric Oxygen Extraction	•	•	•	•	•
Phobos/Deimos Water Extraction	•	•	•	•	•
Propellant Storage and Transfer	•	•	•	•	•
RLSS Supporting Technologies	•	•	•	•	•
Trace Contaminant Control	•		•	•	•
Waste Management	•		•	•	•
Water Recovery/Management	•		•	•	•
Atmosphere Revitalization	•		•	•	•
Food Production	•	•	•	•	•

TABLE 2.2-II CROSSCUTTING TECHNOLOGIES - SPACE TRANSPORTATION

Technology	Automation	Robotics	Maintainability	Operability	FDIR
Chemical Ascent/Descent Engine	•		•	•	•
Aerocapture (Low Energy @ Earth)	•		•		
Aerocapture (Low Energy @ Mars)	•		•		
Aerocapture (High Energy @ Earth)	•		•		
Aerocapture (Dual use @ Mars/Earth)	•		•		
Artificial Gravity Vehicle	•	•	•	•	•
Art.-g Vehicle Deployment/Control	•	•	•	•	•
Tethers	•		•	•	
Information Management	•		•	•	•
Ka-Band Communication Technology	•		•	•	•
Cryo Fluid Storage/Management	•	•	•	•	•
Cryo Fluid Transfer	•	•	•	•	•
Aero Entry/Landing @ Mars	•		•		•
Autonomous Landing	•	•	•	•	•
Direct Entry @ Earth (High Energy)	•		•		•
Parachute System (Earth/Mars)	•		•	•	•
Radiation Protection	•		•	•	•
Long-Lived Life Support Units	•		•	•	•
Advanced Chemical Transfer Engines	•		•	•	•
In situ Propellant Engines	•		•	•	•
High Power Electric Propulsion	•		•	•	•
Nuclear Power for NEP	•		•	•	•
Solar Power for SEP (MW class)	•		•	•	•
Nuclear Thermal Rocket Propulsion	•		•	•	•

TABLE 2.2-III CROSSCUTTING TECHNOLOGIES - NODE

Technology	Automation	Robotics	Maintainability	Operability	FDIR
In-Space Vehicle Processing/Servicing	•	•	•	•	•
Cryo Fluid Storage/Management	•	•	•	•	•
Cryo Fluid Transfer/Handling	•	•	•	•	•
In-Space Assembly - Vehicle Level	•	•	•	•	•
Autonomous Rendezvous/Docking	•	•	•	•	•
In-Space Assembly - Element Level	•	•	•	•	•

2.3 Critical Technologies Summary

Technology requirements are not pathway dependent, but assume application for either the lunar or Mars case studies. The evolutionary case studies allow the formulation of a technology development effort that is phased. The critical technology areas required to support a phased program are listed in table 2.3-I. The listed critical technologies are those that are critical to the lunar or martian exploration pathway as indicated by the check marks in table 2.3-I and must be started in FY91. A short summary describing the scope and benefit of the near term critical technologies is provided.

TABLE 2.3-I CRITICAL TECHNOLOGY NEEDS

Technology	Lunar	Mars
Near Term Enabling		
Life Support Systems	✓	✓
EVA Systems Technology	✓	✓
Radiation Protection	✓	✓
Cryogenic Fluid Management	✓	✓
Cryogenic Ascent/Descent Engine	✓	✓
Near Term Enabling - Affordability		
Efficient Space Transportation System	✓	✓
In-Space Vehicle Operations	✓	✓
Mid Term Enabling		
Nuclear Surface Power (< 1 MWe)	✓	✓
Surface Transportation Technology	✓	✓
In situ Resource Utilization	✓	✓
Far Term Enhancing		
Aerobraking (High Energy)		✓
Nuclear/Solar Electric Propulsion		✓
Nuclear Thermal Rocket (Gas Core)		✓

2.3.1 Life Support Systems

No function is more critical to human exploration than that of sustaining human life. The emphasis here is on providing the technologies that will enable life support systems for long duration spaceflight, lunar bases, and Mars outposts. These life support systems must satisfy the following criteria:

- highly reliable over long time periods
- require minimum, simple maintenance
- achieve a "reasonable" degree (95%+) of closure and are capable of taking advantage of local resources

While the environmental control and life support system (ECLSS) approach planned for Space Station Freedom (SSF) is acceptable approach for the space station, the maintenance approach (reliability requirements are met by frequent scheduled maintenance and component replacement) will not be acceptable for exploration missions. Therefore, advancements in technology are needed to assess other approaches for meeting reliability requirements.

It is recommended that in-depth conceptual definitions continue to be conducted in FY90 to define the specific ECLSS needed for each specific system. An integrated technology development plan needs to be developed which includes physical/chemical, hybrid, and bioregenerative life support approaches.

2.3.2 EVA Systems Technology

Advancement in technology is required to develop the suits and portable life support systems required to perform the EVA operations on both the Moon and Mars. The key issues that the technology program must address are:

- Weight (both the suit weight and PLSS)
- Flexibility, ease of use
- Long duration use (up to 8 hours)

Servicing of the current suit is required after every 21 hours of use. The servicing takes approximately 2,100 hours to complete. This time intensive servicing schedule is unacceptable for a productive lunar base.

2.3.3 Radiation Protection

An integrated approach needs to be developed to clearly establish the technology needs to protect humans, and sensitive equipment, from a variety of radiation hazards in space. These hazards include:

- Trapped particles in the van Allen belts
- solar particle events (SPE)
- galactic cosmic rays (GCR)
- nuclear reactor emissions

In particular, the impact of GCR radiation potentially has significant impacts, requiring massive amounts of shielding. Due to uncertainties in the current computation models for predicting the transport of radiation through materials, the estimates of required shielding can vary by a factor of

10 or more. For example, the shield mass required for the Mars Transfer Vehicle (MTV) in the FY89 Mars Expedition case study varies from 60 to 800 metric tons, which more than exceeds the total mass in low Earth orbit (LEO) of the unshielded vehicle (see figure 2.3.3-1.) The uncertainties in shielding mass can be reduced by a more accurate definition of the free space environment, transport through materials and advancement in the state of the art in computational models to provide more reliable, accurate predictions. Lightweight materials need to be developed to provide adequate shielding and life science research is needed to establish safe annual and career limits.

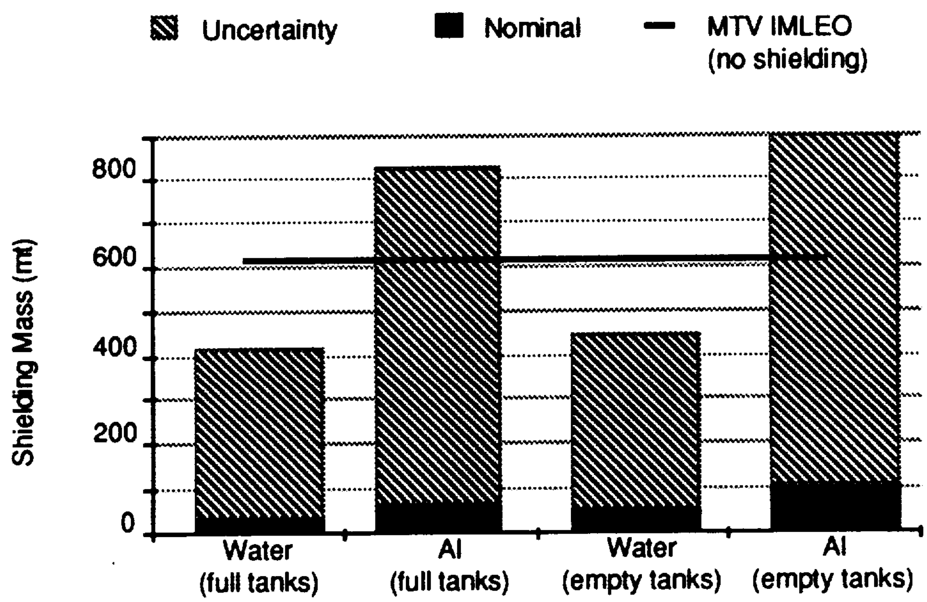


Figure 2.3.3-1. Radiation shielding comparison for the Mars Transfer Vehicle.

2.3.4 Cryogenic Fluid Management

Virtually every approach developed to date has required the transfer and storage of propellant, either via actual fluid transfer between tanks, or via transfer of the tank itself. Large scale transfer has not been demonstrated in space, and must be successfully accomplished to enable missions to either the Moon or Mars.

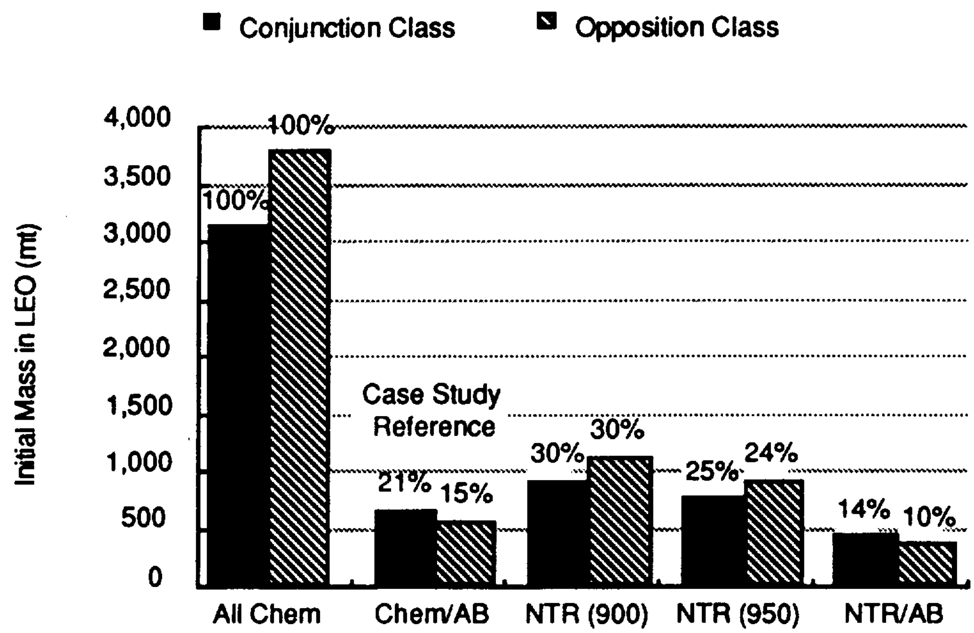
2.3.5 Cryogenic Ascent/Descent Propulsion

OEXP studies have identified a need for cryogenic ascent/descent propulsion systems beyond the current state of the art, for both lunar and Mars missions. However, storable systems may be preferable for Mars ascent/descent stages if significant quantities of in situ propellant were not readily available. The technology issues associated with satisfying the cryogenic ascent/descent requirements for the Moon and Mars are:

- Long life in terms of number of starts and total burn times
- High reliability with little or no maintenance
- Throttlable over a wide range (20:1)
- Thrust ranges of 33.4 kN (7.5 klb) to 222.5 kN (50 klb)
- Permit use of in situ produced propellants

2.3.6 Efficient Space Transportation Systems

Studies conducted in recent years have identified the need to make substantial reductions in the initial mass in LEO required for lunar and Mars missions when using all chemical propulsive approaches. While these missions could technically be accomplished using such an approach, the very large mass in LEO would probably make them economically infeasible. Thus from an affordability perspective, two approaches are currently under consideration. These approaches are Advanced Chemical propulsion with Aerocapture and Nuclear Thermal Rocket propulsion. Figure 2.3.6-1 shows that the use of these approaches may yield reductions of mass in LEO in the range of 70 to 85% (i.e., 2,600-3,200 metric tons) for Mars missions. Sections 2.3.6.1 through 2.3.6.3 summarize the technology needs for these approaches.



Ref: LeRC ASAO, "Advanced Propulsion Comparison Study", WGW #4 Briefing, July 12, 1989

Figure 2.3.6-1. Comparison of IMLEO using different propulsion systems for Mars missions. [NTR(900) is a 900 Isp propulsion system, NTR(950) is a 950 Isp propulsion system, and NTR/AB is a 900 Isp propulsion system using an aerobrake.]

2.3.6.1 Advanced Chemical Transfer Propulsion ≤ 445 kN (100 klb)

Advances in chemical propulsion beyond the state-of-the-art (Centaur RL-10) is needed for lunar and Mars space transfer vehicles. While an increase in Isp over 460 will yield significant benefits, the driving needs for advancement are reliability and maintainability. The success of the mission profile will require propulsion systems with inherent restart and automated self-diagnosis/failure prediction capabilities.

A wide range of thrust-levels have been considered for lunar and Mars space transfer systems. As indicated below, a reasonably consistent need has emerged for engines in the thrust range below 445 kN (100 klbs). The need for higher thrust levels was driven by the Trans Mars Injection Stage (TMIS) requirements.

Low Thrust < 445 kN (100 klbs)
lunar: 66.75-111 kN (15-25 klbs)
Mars: 33.4-111 kN (7.5-25 klbs)
High Thrust 445-2225 kN (100-500 klbs)
Mars: 667.5-2225 kN (150-500 klbs)

More study is required to understand the trade-off between thrust/engine and number of engines needed for high thrust requirements. Three options are:

1335-2225 kN (300-500 klbs)	One very large engine (derived from the SSME)
333.75-445 kN (75-100 klbs)	Either an engine cluster (3-6 engines) or a single engine with multiple burns
66.75-111 kN (15-25 klbs)	An engine cluster (4-8 engines) with multiple burns

2.3.6.2 Aerocapture

Aerobraking (A/B) will significantly reduce energy requirements making lunar and Mars missions affordable. Use of low energy (≤ 11 km/sec) aerobraking at Mars and at Earth results in a reduction of 64% or more in initial mass to low Earth orbit (IMLEO) over all propulsive entry. This requires a propulsive ΔV of ~ 2 km/sec prior to Earth A/B. Use of high energy (≥12 km/sec) A/B at Earth saves an additional 15% IMLEO (see figure 2.3.6.2-1), but puts the vehicle in a much different aerothermodynamic regime, requiring a major advancement in technology development.

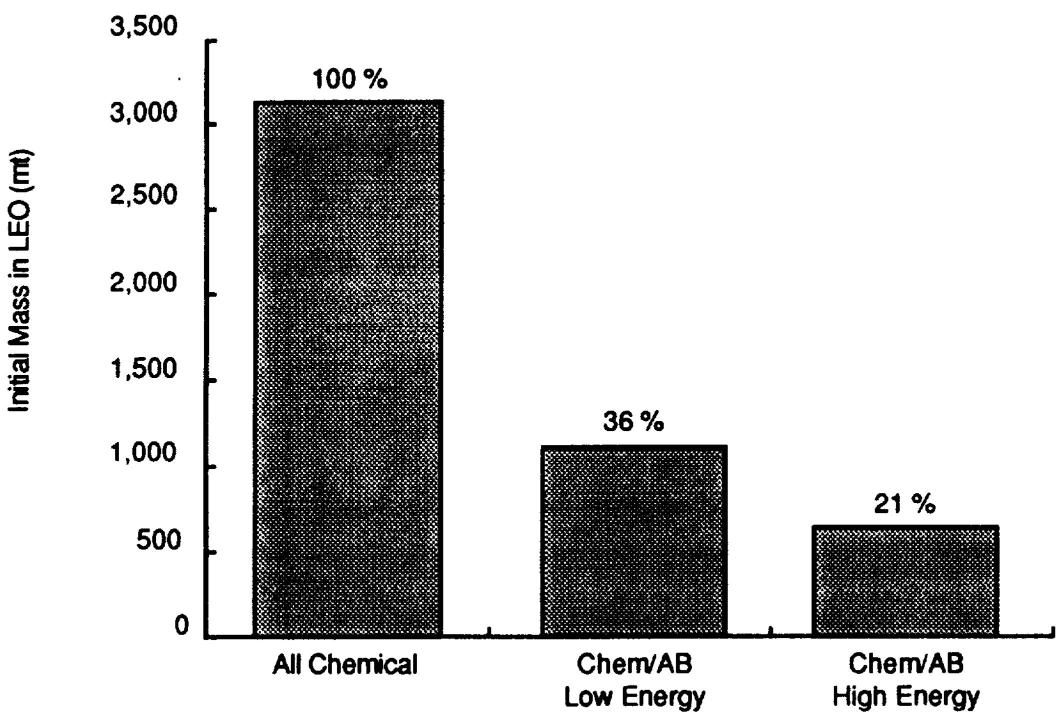


Figure 2.3.6.2-1. Comparison of IMLEO using high and low energy aerobraking and all propulsive systems for Mars missions.

The A/B technology issues are non-equilibrium radiation heating, thermal protection system (TPS), and guidance, navigation and control (GN&C). The Aeroassist Flight Experiment (AFE) (funded in the Civil Space Technology Initiative (CSTI) program) is an important step in developing the technology for low energy A/B.

2.3.6.3 Nuclear Thermal Rocket propulsion (NTR)

Although NTR propulsion has been associated with Mars missions due to fast trip times and low IMLEO (see figure 2.3.6-1), but is only occasionally discussed in Lunar applications. In order to examine the value of NTR propulsion in support of a lunar base initiative four mission scenarios were analyzed. Figure 2.3.6.3-1 summarizes the results of this analysis and shows that IMLEO can be reduced by 50% for lunar missions.

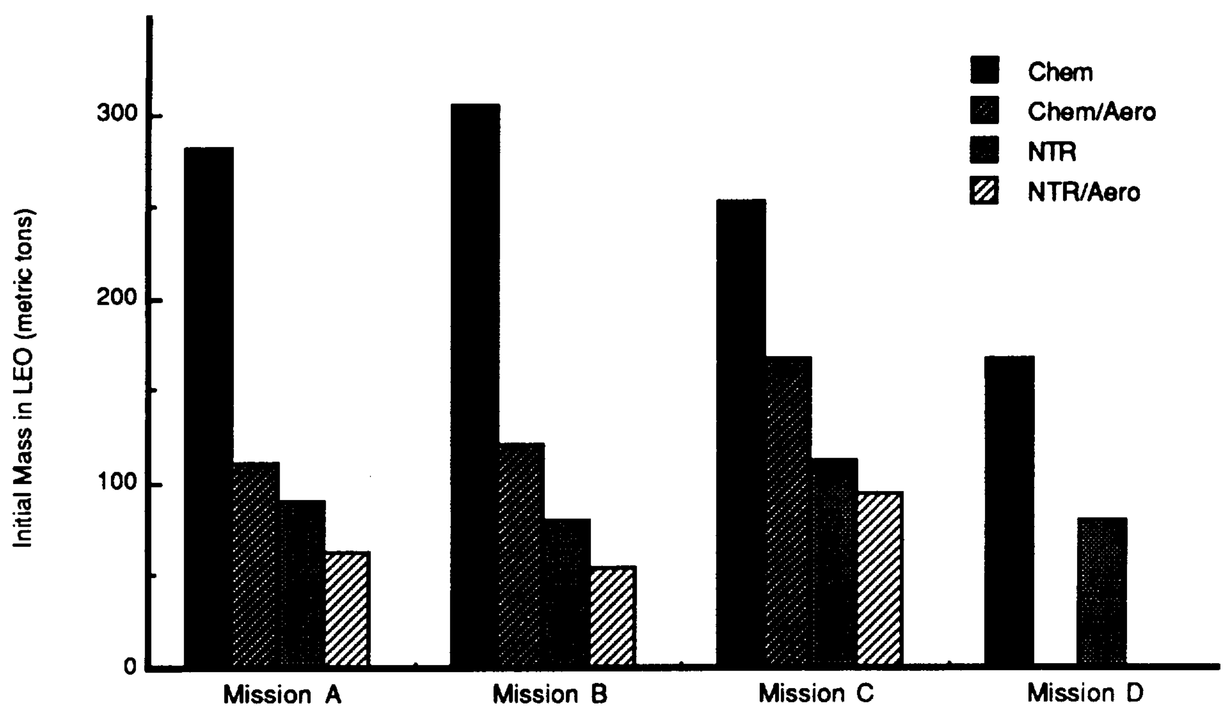


Figure 2.3.6.3-1. Comparison of IMLEO using chemical or NTR propulsion for lunar missions.

Mission A: 20 metric tons of payload is delivered round trip from LEO to low lunar orbit (LLO)

Mission B: 10 metric tons of payload is delivered round trip from LEO to the lunar surface

Mission C: 10 metric tons of payload is delivered round trip from LEO to LLO, and 30 metric tons of cargo is delivered one way from LEO to LLO

Mission D: 30 metric tons of cargo is delivered one way from LEO to the lunar surface

2.3.7 In-Space Vehicle Operations

While the lunar transfer vehicles are being designed to minimize the in-space assembly requirements, the current requirements specify capabilities of the vehicles and Space Station Freedom that have not been demonstrated to date. These systems must have the capability to manipulate, mate, and join large heavy and complex spacecraft elements such as assembling the aerobrake from several large sections, attaching the aerobrake to the vehicle, and mating separate elements of the vehicle together.

2.4 Assessment of Need verses Availability

In developing the scope and strategy for the FY91 space technology program and budget, it is informative to compare the readiness need level and date for each technology with the projected available level and date for the appropriate technology program. Table 2.4-I shows the need level and date for each technology with the projected available level and date for both FY90 funding levels and unconstrained funding for the appropriate technology program. Those technologies that will not be available in time to support the OEXP study mission are denoted by a † assuming a FY90 OAST budget runout or a ‡ assuming unconstrained funding. In projecting the availability of a technology, the existing OAST technology programs were evaluated for consistency of content with the technology needs. There are several technology needs that are not covered by any of the existing programs. In addition, there are technology needs that are covered by existing technology programs, but the programs are not focused to include all aspects of the needed technology. In these cases the appropriate program to address the technology need has been identified and designated as NFP/No Focused Program.

A summary of the current applicable technology programs are presented in section 3.

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
PLANETARY SURFACE SYSTEMS

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Atmosphere Revitalization	89-CS-4.1	‡† 4	0	‡ 6	0	PF/P/C LSS	2000			5	1998
	89-CS-5.0	‡† 4	1996	‡ 6	1998	PF/B/R REQ				0	0
						OSSA/LS/CELSS	1998	2013	0	7	2005
Construction Technology	89-CS-4.1	4	1996	6	1998	CSTI/ROBOTICS				0	0
	89-CS-5.0	4	1996	6	1998	NP/No Program				0	0
Dust Contamination Control	89-CS-4.1	4	1997	6	1998	NP/No Program				0	0
	89-CS-5.0	† 4	1995	6	1997	PF/EVA/SUIT	1998			6	1997
Essential Element Extraction	89-CS-4.1	4	2007	6	2009	NFP/No Focused Prog				0	0
						PF/ISRU	2002			6	1997
EVA Systems Technology	89-CS-4.1	4	1997	6	1998	PF/EVA/SUIT	1998			6	1997
	89-CS-5.0	† 4	1995	6	1997						
Food Production	89-CS-4.1	‡ 4	1997	‡ 6	1999	PF/B/R REQ				0	0
	89-CS-5.0	‡ 4	1996	‡ 6	1998	OSSA/LS/CELSS	1998	2013	0	7	2005
Inflatable Structures	89-CS-4.1	4	1997	6	1999	CSTI/ROBOTICS				0	0
	89-CS-5.0	4	2006	6	2008	NP/No Program				0	0
Lunar Ceramics Production	89-CS-4.1	4	2007	6	2009	NFP/No Focused Prog				0	0

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
PLANETARY SURFACE SYSTEMS

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Lunar Hydrogen Production	89-CS-4.1	4	2007	6	2009	PF/ISRU	2002			6	1997
Lunar Metals Production	89-CS-4.1	4	2007	6	2009	PF/ISRU	2002			6	1997
	89-SA-2.2	† 4	1996	6	2000						
Lunar Oxygen Production	89-CS-4.1	† 4	1996	6	1998	PF/ISRU	2002			6	1997
Mars Atmospheric Oxygen Extraction	89-CS-5.0	4	2005	6	2007	NFP/No Focused Prog				0	0
						PF/ISRU	2002			6	1997
Mars Water Extraction	89-CS-5.0	4	2005	6	2010	NFP/No Focused Prog				0	0
						PF/ISRU	2002			6	1997
Mineral Beneficiation	89-CS-4.1	4	2007	6	2009	PF/ISRU	2002			6	1997
	89-CS-5.0	† 4	1999	6	2001						
Mining Technology	89-CS-4.1	4	1996	6	1998	NFP/No Focused Prog				0	0
	89-CS-5.0	4	1996	6	1998	CSTI/ROBOTICS				0	0
Mobile Power Systems	89-CS-4.1	‡† 4	0	6	0	NFP/No Focused Prog				0	0
	89-CS-5.0	† 4	1996	6	1998	PF/ROVER	2001			6	1996
	89-SA-1.5	4	2002	6	2004						

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
PLANETARY SURFACE SYSTEMS

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Phobos/Deimos Water Extraction	89-CS-5.0	† 4	1999	6	2001	NFP/No Focused Prog				0	0
						PF/ISRU	2002			6	1997
Propellant Storage and Transfer	89-CS-4.1	† 4	1997	6	1999	PF/CFD	2000			0	1998
	89-CS-5.0	4	2002	6	2004	NFP/No Focused Prog				0	0
RLSS Supporting Technologies	89-CS-4.1	‡† 4	1997	‡ 6	1999	PF/B/R REQ				0	0
	89-CS-5.0	‡† 4	1996	6	1998	PF/P/C LSS	2000			5	1998
						OSSA/LS/CELSS	1998	2013	0	7	2005
Surface Power < 1 MWe	88-SA-1.2	4	1997	6	1999	PF/SURF POWER	1998	2002		6	1997
	89-CS-4.1	† 4	1994	6	1996	PF/SP-100	1996		2000	6	1996
	89-CS-5.0	† 4	1995	6	1997						
	89-SA-1.7	‡† 4	1992	6	1995						
Surface Power > 1 MWe	89-CS-4.1	4	1998	6	2000	DOE MMW/MMW				0	0
	89-CS-5.0	4	1999	6	2001	CSTI/HIGH CAP PWR				6	2002
	89-SA-1.10	4	1998	6	2000	NFP/No Focused Prog				0	0
Surface Transport Technology	89-CS-4.1	‡† 4	0	6	0	NFP/No Focused Prog				0	0
	89-CS-5.0	† 4	1996	6	1998	CSTI/ROBOTICS				0	0
	89-SA-1.5	4	2002	6	2004	PF/ROVER	2001			6	1996
						CSTI/AUTO SYS	1993		1989	0	0

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
PLANETARY SURFACE SYSTEMS

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Thermal Control	89-CS-4.1	‡ 4	0	6	0	NFP/No Focused Prog				0	0
	89-CS-5.0	‡ 4	1996	6	1998	CSTI/HIGH CAP PWR				6	2002
Trace Contaminant Control	89-CS-4.1	‡† 4	0	‡ 6	0	PF/P/C LSS	2000			5	1998
	89-CS-5.0	‡† 4	1996	‡ 6	1998	PF/B/R REQ				0	0
						OSSA/LS/CELSS	1998	2013	0	7	2005
Waste Management	89-CS-4.1	‡† 4	1997	‡ 6	1999	PF/P/C LSS	2000			5	1998
	89-CS-5.0	‡† 4	1996	‡ 6	1998	PF/B/R REQ				0	0
						OSSA/LS/CELSS	1998	2013	0	7	2005
Water Recovery/Management	89-CS-4.1	‡† 4	1997	‡ 6	1999	PF/P/C LSS	2000			5	1998
	89-CS-5.0	‡† 4	1996	‡ 6	1998	PF/B/R REQ				0	0
						OSSA/LS/CELSS	1998	2013	0	7	2005

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY TRANSPORTATION

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Advanced Chemical Propulsion	88-CS-1.0	† 4	1992	6	1995	PF/CHEM TRANS	1999			6	1996
	88-CS-2.0	† 4	1996	6	1999						
	88-CS-3.0	† 4	1992	6	1995						
	88-CS-4.0	4	1999	6	2002						
	89-CS-2.1	† 4	1994	6	1996						
	89-CS-5.0	† 4	1994	6	1997						
Aero Entry/Landing @ Mars	89-CS-5.0	4	1994	6	1998	NFP/No Focused Prog				0	0
						PF/HEAB				4	1994
Aerocap (Dual use @ Mars/ Earth)	89-CS-5.0	4	2001	6	2005	PF/HEAB				4	1994
						NFP/No Focused Prog				0	0
AeroCap (Low Energy)@ Earth	89-CS-4.1	4	1996	6	1998	PF/HEAB				4	1994
	89-CS-5.0	4	2001	6	2005	CSTI/AFE	1994	1995		0	0
AeroCap (Low Energy)@Mars	89-CS-2.1	4	1994 ‡	6	1996	PF/HEAB				4	1994
	89-CS-5.0	4	2001	6	2005						
Aerocapture (High Energy)@ Earth	88-CS-2.0	4	1996	6	1999	PF/HEAB				4	1994
	88-CS-4.0	4	1999	6	2002						
	89-CS-2.1	4	1994 ‡	6	1996						
	89-CS-5.0	4	2001	6	2005						

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY TRANSPORTATION

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Advanced Chemical Propulsion	88-CS-1.0	† 4	1992	6	1995	PF/CHEM TRANS	1999			6	1996
	88-CS-2.0	† 4	1996	6	1999						
	88-CS-3.0	† 4	1992	6	1995						
	88-CS-4.0	4	1999	6	2002						
	89-CS-2.1	† 4	1994	6	1996						
	89-CS-5.0	† 4	1994	6	1997						
Aero Entry/Landing @ Mars	89-CS-5.0	4	1994	6	1998	NFP/No Focused Prog				0	0
						PF/HEAB				4	1994
Aerocap (Dual use @ Mars/ Earth)	89-CS-5.0	4	2001	6	2005	PF/HEAB				4	1994
						NFP/No Focused Prog				0	0
AeroCap (Low Energy)@ Earth	89-CS-4.1	4	1996	6	1998	PF/HEAB				4	1994
	89-CS-5.0	4	2001	6	2005	CSTI/AFE	1994	1995		0	0
AeroCap (Low Energy)@Mars	89-CS-2.1	4	1994	‡ 6	1996	PF/HEAB				4	1994
	89-CS-5.0	4	2001	6	2005						
Aerocapture (High Energy)@ Earth	88-CS-2.0	4	1996	6	1999	PF/HEAB				4	1994
	88-CS-4.0	4	1999	6	2002						
	89-CS-2.1	4	1994	‡ 6	1996						
	89-CS-5.0	4	2001	6	2005						

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
TRANSPORTATION

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Artificial Gravity Vehicle	89-CS-5.0	4	2001	6	2005	PF/CREW PROT	2000			4	1996
						PF/SP HUM FCTRS				4	1995
						NFP/No Focused Prog				0	0
						PF/HUM PERFORM				0	1997
Artificial-g Vehicle Deployment &	89-CS-5.0	4	2001	6	2005	NP/No Program				0	0
Autonomous Landing	89-CS-4.1	† 4	1996	6	1998	PF/AUTO LANDER	2000			6	1996
	89-CS-5.0	† 4	1994	6	1997						
Chemical Ascent/Descent Propulsion	88-CS-2.0	† 4	1994	6	1997	PF/CHEM TRANS	1999			6	1996
	88-CS-3.0	† 4	1992	6	1995						
	88-CS-4.0	† 4	1996	6	1999						
	89-CS-2.1	† 4	1993	6	1995						
	89-CS-4.1	† 4	1996	6	1998						
	89-CS-5.0	† 4	1994	6	1997						
Cryo Fluid Storage/Management	89-BT-5	† 4	1996	6	1998	COLDSAT/COLDSAT				0	0
	89-CS-2.1	† 4	1994	6	1996	PF/CFD	2000			0	1998
	89-CS-4.1	† 4	1996	6	1998						
	89-CS-5.0	4	2001	6	2005						
	89-SA-1	4	2003	6	2005						

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY TRANSPORTATION

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Cryo Fluid Supply/Transfer	89-BT-5	† 4	1996	6	1998	COLDSAT/COLDSAT				0	0
	89-CS-2.1	† 4	1994	6	1996	PF/CFD	2000			0	1998
	89-CS-4.1	† 4	1996	6	1998						
	89-CS-5.0	4	2001	6	2005						
	89-SA-1	4	2003	6	2005						
Direct Entry @ Earth (High Energy)	89-CS-2.1	4	1994	6	1996	NP/No Program				0	0
GCR Radiation Protection	88-CS-1.0	† 4	1992	6	1995	NFP/No Focused Prog				0	0
	88-CS-2.0	† 4	1996	6	1999	PF/SP HUM FCTRS				4	1995
	88-CS-4.0	4	1999	6	2002	PF/HUM PERFORM				0	1997
	89-CS-2.1	† 4	1994	6	1996	PF/CREW PROT	2000			4	1996
	89-CS-5.0	4	2001	6	2005						
High Power Electric Propulsion	89-CS-5.0	† 4	2001	6	2005	PF/CV PROP	2004			7	1998
	89-SA-1	4	2003	6	2005						
In situ Propellant Engines	89-CS-4.1	† 4	1996	6	1998	NFP/No Focused Prog				0	0
	89-CS-5.0	† 4	1994	6	1997	PF/CHEM TRANS	1999			6	1996
Information Management	89-CS-2.1	4	1992	6	1996	CSTI/DATA CAPACITY				4	1992
	89-CS-4.1	4	1995	6	1999						
	89-CS-5.0	4	1994	6	1998						

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY TRANSPORTATION

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Ka-Band Communications Technology	89-CS-2.1	4	1992	6	1996	CSTI/DATA CAPACITY				4	1992
	89-CS-4.1	4	1995	6	1999						
	89-CS-5.0	4	1994	6	1998						
Long-lived Life Support Units	89-CS-2.1	‡† 4	1994	‡ 6	1996	PF/B/R REQ				0	0
	89-CS-5.0	4	2001	6	2005	PF/P/C LSS	2000			5	1998
	89-SA-2	4	2000	6	2002						
Nuclear Power for NEP	88-CS-4.0	‡† 4	1994	6	1996	CSTI/HIGH CAP PWR				6	2002
	89-CS-4.1	‡† 4	1996	6	1998	PF/SP-100	1996		2000	6	1996
	89-CS-5.0	† 4	2001	6	2005	PF/CV PROP	2004			7	1998
Nuclear Thermal Rocket Propulsion	89-CS-5.0	4	2001	6	2005	PF/SP-100	1996		2000	6	1996
	89-SA-2	4	2000	6	2002	NFP/No Focused Prog				0	0
						CSTI/HIGH CAP PWR				6	2002
Parachute System (Earth/Mars)	89-CS-2.1	4	1994	6	1996	NP/No Program				0	0
	89-CS-5.0	4	1994	6	1997						
Solar Power for SEP	89-SA-1	4	2003	6	2005	NP/No Program				0	0
Tethers	89-CS-5.0	4	1998	6	2000	NP/No Program				0	0

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

ASSESSMENT of TECHNOLOGY NEED vs. AVAILABILITY
NODE SYSTEMS

Technology	Case Study	Need Level / Date				Projected Available Level & Date					
		Phase B		Phase C/D		Technology Program/Element	FY90 Funding Readiness			Unconstrained Readiness	
		Level	Date	Level	Date		5	6	7	Level	Date
Autonomous Rend. & Docking	88-CS-1.0	† 4	1992	6	1995	PF/AUTO R&D	1996		1998	7	1994
	88-CS-2.0	† 4	1992	6	1995						
	88-CS-3.0	4	1999	6	2002						
	89-CS-2.1	4	1999	6	2002						
	89-CS-4.1	4	1996	6	1998						
	89-CS-5.0	4	1999	6	2002						
Cryo Fluid Storage/Management						COLDSAT/COLDSAT				0	0
						PF/CFD	2000			0	1998
Cryo Fluid Supply/Transfer						COLDSAT/COLDSAT				0	0
						PF/CFD	2000			0	1998
In-Space Assy - Vehicle Level	88-CS-2.0	† 4	1996	6	1999	CSTI/ROBOTICS				0	0
	89-CS-5.0	† 4	1994	6	1997	PF/IN-SP A&C	2002		2005	7	1996
In-Space Assy.-Element Lev.	88-CS-2.0	† 4	1996	6	1999	CSTI/ROBOTICS				0	0
	89-CS-4.1	† 4	1994	6	1996	PF/IN-SP A&C	2002		2005	7	1996
	89-CS-5.0	† 4	1994	6	1997						
In-Space Vehicle Processing/Servicing	88-CS-4.0	4	1999	6	2002	CSTI/AUTO SYS	1993		1989	0	0
	89-CS-4.1	4	1996	6	1998	CSTI/ROBOTICS				0	0
	89-CS-5.0	4	1994	6	1997	NFP/No Focused Prog				0	0

† Not available in time based on FY90 OAST budget runout

‡ Not available even with unconstrained budget

TABLE 2.4-II CASE STUDY KEY

88-CS-1.0	1988 Expedition to Phobos case study
88-CS-2.0	1988 Expedition to Mars case study
88-CS-3.0	1988 Lunar Observatory case study
88-CS-4.0	1988 Lunar Outpost to Early Mars Evolution case study
88-SA-1.1	Lunar SP-100/Stirling Engine Design special assessment
88-SA-1.2	Lunar Observatory Extended Stay Time Power special assessment
89-BT-5	Fuel System Architecture broad trade study
89-CS-2.1	1989 Mars Expedition case study
89-CS-4.1	1989 Lunar Evolution case study
89-CS-5.0	1989 Mars Evolution case study
89-SA-1	Power special assessment
89-SA-1.5	Manned High Power Rover special assessment
89-SA-1.7	SP-100 Thermoelectric Lander special assessment
89-SA-1.10	MMW Power Plant special assessment
89-SA-1.11	Low Power Robotic Rover special assessment
89-SA-2	Propulsion special assessment
89-SA-2.2	In Situ Propellant Utilization special assessment
89-SA-2.3	Advanced Propulsion options study
89-SA-3	A&R Human Performance special assessment

TABLE 2.4-III TECHNOLOGY PROGRAM KEY

CSTI/AFE	Civil Space Technology Initiative - Aeroassist Flight Experiment
CSTI/AUTO SYS	Civil Space Technology Initiative - Autonomous Systems
CSTI/BOOSTR TECH	Civil Space Technology Initiative - Booster Technology
CSTI/CNTL FLEX STR	Civil Space Technology Initiative - Control of Flexible Structures
CSTI/DATA CAPACITY	Civil Space Technology Initiative - High Rate/Capacity Data Systems
CSTI/ETO PROP	Civil Space Technology Initiative - Earth to Orbit Propulsion
CSTI/HIGH CAP PWR	Civil Space Technology Initiative - High Capacity Power
CSTI/PREC SEG REFL	Civil Space Technology Initiative - Precision Segmented Reflectors
CSTI/ROBOTICS	Civil Space Technology Initiative - Robotics
CSTI/SENSORS	Civil Space Technology Initiative - Science Sensor Technology
DOE MMW/MMW	Department of Energy - Multi-MegaWatt Power Program
NFP/No Focused Prog	Program not focused to exploration needs
NP/No Program	No Program Exists
PF/AUTO LANDER	Pathfinder - Autonomous Lander
PF/AUTO R&D	Pathfinder - Autonomous Rendezvous & Docking
PF/B/R REQ	Pathfinder - Bioregenerative Life Support
PF/CFD	Pathfinder - Cryogenic Fluid Depot
PF/CHEM TRANS	Pathfinder - Chemical Transfer Propulsion
PF/CREW PROT	Pathfinder - Crew Protective Systems
PF/CV PROP	Pathfinder - Cargo Vehicle Propulsion
PF/EVA/SUIT	Pathfinder - Extravehicular Activity/Suit
PF/HEAB	Pathfinder - High Energy Aerobraking
PF/HUM PERFORM	Pathfinder - Human Performance
PF/IN-SP A&C	Pathfinder - In-Space Assembly & Construction
PF/ISRU	Pathfinder - Resource Processing Pilot Plant
PF/OPTCL COMM	Pathfinder - Optical Communications
PF/P/C LSS	Pathfinder - Physical-Chemical Life Support
PF/PHOTONICS	Pathfinder - Photonics
PF/ROVER	Pathfinder - Planetary Rover
PF/SAAP	Pathfinder - Sample Acquisition, Analysis, & Preservation
PF/SP HUM FCTRS	Pathfinder - Space Human Factors
PF/SP-100	Pathfinder - Space Nuclear Power
PF/SURF POWER	Pathfinder - Surface Power

2.5 Summary of Technology Needs by Integration Agent

Tables 2.5-I to 2.5-III present a listing of the same technology needs as section 2.1 sorted by IA. These technologies are discussed by the IA's in their respective volumes (II through IV).

TABLE 2.5-I TECHNOLOGY NEEDS - **PLANETARY SURFACE SYSTEMS**

Technology	Ranking			Functional Area
Construction technology	I	A	2	CONSTRUCTION
Surface Transportation Technology	I	A	2	CONSTRUCTION
Inflatable Structures	III	B	2	CONSTRUCTION
Surface Power (< 1 MWe)	I	A	3	ENERGY
Mobile Power Systems	III	A	2	ENERGY
Thermal Control	III	A	2	ENERGY
Surface Power (> 1 MWe)	I	C	2	ENERGY
EVA Systems Technology	I	A	3	Human Systems
Dust Contamination Control	III	A	3	Human Systems
Lunar Oxygen Production	II	B	2	ISRU
Mining Technology	II	B	2	ISRU
Mars Water Extraction	II	B	2	ISRU
Mineral Beneficiation	III	B	3	ISRU
Essential Element Extraction	III	C	2	ISRU
Lunar Ceramics Production	IV	C	2	ISRU
Lunar Hydrogen Production	IV	C	2	ISRU
Lunar Metals Production	IV	C	2	ISRU
Mars Atmospheric Oxygen Extraction	IV	C	2	ISRU
Phobos/Deimos Water Extraction	IV	C	2	ISRU
Propellant Storage and Transfer	III	B	2	LAUNCH & LAND
RLSS Supporting Technologies	I	A	2	LSS
Trace Contaminant Control	I	A	2	LSS
Waste Management	I	A	2	LSS
Water Recovery/Management	I	A	2	LSS
Atmosphere Revitalization	I	A	3	LSS
Food Production	I	C	2	LSS

TABLE 2.5-II TECHNOLOGY NEEDS - SPACE TRANSPORTATION

Technology	Ranking			Functional Area
Chemical Ascent/Descent Engine	I	A	3	A/D CHEM PROP
Aerocapture (Low Energy @ Earth)	I	A	2	AEROCAPTURE
Aerocapture (Low Energy @ Mars)	II	A	2	AEROCAPTURE
Aerocapture (High Energy @ Earth)	IV	A	2	AEROCAPTURE
Aerocapture (Dual use @ Mars/Earth)	IV	C	1	AEROCAPTURE
Artificial Gravity Vehicle	IV	A	2	ARTIFICIAL-G SYS
Artificial-g Vehicle Deployment and Control	IV	A	3	ARTIFICIAL-G SYS
Tethers	IV	A	3	ARTIFICIAL-G SYS
Information Management	III	A	3	COMMUNICATION
Ka-Band Communications Technology	III	A	3	COMMUNICATION
Cryo Fluid Supply/Storage/Management	I	A	3	CRYO FLUID MGT
Cryo Fluid Transfer	I	A	3	CRYO FLUID MGT
Aero Entry/Landing @ Mars	II	A	2	ENTRY SYSTEMS
Autonomous Landing	III	A	2	ENTRY SYSTEMS
Direct Entry @ Earth (High Energy)	IV	A	2	ENTRY SYSTEMS
Parachute System (Earth/Mars)	IV	A	3	ENTRY SYSTEMS
Radiation Protection	I	A	2	Human Systems
Long-Lived Life Support Units	I	A	3	LSS
Advanced Chemical Transfer Engines	I	A	3	STV CHEM PROP
In situ Propellant Engines	IV	C	2	STV CHEM PROP
High Power Electric Propulsion (MW class)	III	C	2	STV ELEC PROP
Nuclear Power for NEP	III	C	2	STV ELEC PROP
Solar Power for SEP (MW class)	IV	C	2	STV ELEC PROP
Nuclear Thermal Rocket Propulsion	II	A	3	STV NTR PROP

TABLE 2.5-III TECHNOLOGY NEEDS - NODE

Technology	Ranking			Functional Area
Cryo Fluid Supply/Storage/Management	I	A	3	CRYO FLUID MGT
Cryo Fluid Transfer/Handling	I	A	3	CRYO FLUID MGT
In-Space Vehicle Processing/Servicing	I	A	2	In-Space Ops
In-Space Assembly - Vehicle Level	II	A	2	In-Space Ops
Autonomous Rendezvous and Docking	III	A	1	In-Space Ops
In-Space Assembly - Element Level	III	A	2	In-Space Ops

3 Technology Program Summary

This section summarizes the technology programs which are applicable to the lunar and Mars exploration program. As shown in section 2.4, existing programs are insufficient to produce the required technologies in the required time frame. The Pathfinder and CSTI programs have the most direct applicability to human space exploration. Pathfinder is a NASA initiative to develop capabilities to enable future exploration missions. CSTI is a focused effort to develop a technology base for future missions with emphasis on efficient, reliable access to and in support of science missions from Earth orbit.

There are several technologies that are needed for human exploration that are not currently covered in a technology program. These include construction technology, inflatable structures, artificial gravity vehicle deployment, high energy direct entry systems, parachute systems, tethers, and solar electric propulsion. There are a number of technology needs that are not fully covered by existing programs. In these case the scope and/or focus of an existing program must be modified to accommodate the specific need. These include ISRU, mining, mobile power, surface propellant storage and transfer, surface power (> 1 MWe), surface transportation, thermal control, in-space vehicle processing and servicing, dual use aerobraking, artificial gravity vehicle design, radiation protection, in situ propellant engines, and nuclear propulsion.

3.1 Pathfinder Element Programs

Pathfinder is a NASA initiative to develop critical capabilities to enable future exploration missions. Key performance-related objectives are to produce critical research results and validate capabilities by 1993 and achieve necessary levels of readiness and transition technologies to mission users commencing in the mid-1990's. Pathfinder consists of four major program areas (Surface Exploration, In Space Operations, Humans in Space, and Space Transfer). Within the four major program areas are 20 element programs. The following subsections contain a brief summary of each of these elements.

3.1.1 Surface Exploration

3.1.1.1 Planetary Rover

Objectives of the planetary rover program are to develop and validate the technologies needed to enable robotic and manned exploration of various planetary surfaces and enhance in situ science. The near-term program will focus on developing selected technologies for robotic rovers, demonstrating those technologies in integrated testbeds and conducting studies of high leverage rover architectures. The areas to be addressed are mobility, autonomous guidance, sampling robotics, and rover power. This program will extend work conducted in FY88-90 at Carnegie Mellon University and builds on terrestrial programs (Department of Defense (DoD), Defense Advanced Research Projects Agency's (DARPA) strategic computing and autonomous land vehicle programs, the VHSIC (very high speed integrated circuit) advanced computing program, and the Department of Energy's (DoE) modular radioisotope thermal generator (RTG) program).

3.1.1.2 Sample Acquisition, Analysis, and Preservation (SAAP)

The SAAP program will develop the technologies required for collection and analysis (both in situ and Earth return) of scientifically valuable specimens from a planet's surface and near-subsurface. These technologies include: site and sample recognition and selection; sample acquisition, preparation, and processing; sample analysis; and storage and preservation. The elements of this program will be integrated for a technology demonstration/validation in the FY 92-94 timeframe. Primary emphasis will be placed on system design, site and sample recognition/selection, sample preparation and analysis methods, rock core drilling, sample acquisition tools, and containment methods. Secondary elements include long-term environmental control, soil coring, and integrated testbeds. Initially, the technology developed will be coordinated with the needs of the Mars Sample Return mission.

3.1.1.3 Autonomous Lander

The Autonomous Lander program will develop and demonstrate the technology needed to land a planetary exploration spacecraft safely in the face of surface hazards provided by rough terrain, while still landing close enough to the target site to meet mission requirements. Plans call for establishing mission constraints and requirements, developing and demonstrating the technology required to enable precision landing at a pre-planned site, and developing and demonstrating the technology for real-time hazard avoidance during the final landing stages (sensors for hazard detection, algorithms for image processing, scene understanding and guidance, real-time image processing, and system autonomy and mechanization are required).

3.1.1.4 Surface Power

The surface power program will develop a technology base that will support the development of planetary surface power systems capable of delivering 25 to 100 kilowatts of user power. In cases of sustained base operations, it is anticipated that the start-up solar power system will later serve as an emergency back-up power source for the expected nuclear power system. The areas to be addressed will involve either photovoltaic or solar dynamic technologies, energy storage technologies which are likely to focus on regenerative fuel cells, and environmental countermeasures.

Energy storage technology for regenerative fuel cells will encompass: high temperature oxygen electrode catalysts, gas/liquid/thermal management systems, and tanks for gaseous reactant storage. Efforts in amorphous silicon photovoltaic cell technology will be directed at increased efficiency, reduced mass, and improved lifetime and reliability. Solar dynamic approaches will be evaluated relative to ongoing programs in concentrators, receivers, and energy conversion systems.

3.1.1.5 Photonics (initiation deferred to 1990)

The photonics program will (1) develop fault tolerant, high data rate networks for space systems such as autonomous spacecraft, interplanetary transfer vehicles, and habitats, (2) enable safe traverses by a rover at higher speeds and lesser power than all-electronic systems by use of optical pattern recognition (note that multi-spectral processors and a Ka-band phased array radar will be developed to support this capability), and (3) enable electronic vision systems for automated landings and have up to three orders of magnitude reduction in processing requirements through the use of a photonics preprocessor. In the latter case, related technologies include photonic sensors, integrated optical switches, fiber optic control of monolithic microwave integrated circuit (MMIC) chips, and image processing architectures. This program will leverage on-going research being conducted by DoD, industry, and universities.

3.1.2 In Space Operations

3.1.2.1 Autonomous Rendezvous and Docking

This program will develop and demonstrate hardware and software technologies and technical approaches for autonomous/automated rendezvous and docking to support lunar and Mars missions. Sensors that have long and short range tracking and relative navigation capability will be developed to meet system requirements. Trajectory control techniques and candidate GN&C

designs will be developed and evaluated in computer simulations and flat floor testbeds and will incorporate sensor concepts proposed for consideration.

3.1.2.2 In-Space Assembly and Construction

This program will develop the basic technology to construct large, massive structures and complex vehicles in space. Objectives of the program are to (1) define and develop methodologies for constructing generic spacecraft components, (2) develop joining processes (welding, bonding, and mechanical attachment), (3) develop the ability to manipulate and position large massive vehicle components, and (4) define a layout and infrastructure for a facility having a high degree of construction flexibility, adaptability, autonomy, and commonality.

3.1.2.3 Cryogenic Fluid Depot

The cryogenic fluid depot program is directed towards development and demonstration of the technology required to store, supply, and transfer subcritical cryogenic liquids in a microgravity environment. Specific objectives include development of depot conceptual designs, fluid management and depot operations, structures and materials, orbital operations and logistics, refrigeration, and safety. This program currently has limited storage and fluids transfer focus.

3.1.2.4 Space Nuclear Power SP-100

The Space Nuclear Power (SP-100) program represents NASA's participation in DoE's GSP-100 Ground Engineering System (GES) Project. This program will develop and validate technology for space nuclear power systems that can produce tens to hundreds of kilowatts of electric power and be capable of 7 years of operational life at full power. This program focuses on lunar and Mars outpost power systems, and Nuclear Electric Propulsion (NEP) robotic solar system exploration.

GES is focused on developing and validating the system through a Nuclear Assembly Test (NAT) and Integrated Assembly Test (IAT). Advancements will be required in several areas, including high temperature (1350 K) refractory alloys, high temperature control devices, thermoelectric-electromagnetic pumps, high efficiency thermoelectric converters, light-weight heat pipe radiators, and power conditioning and control. Safety related aspects of the system are a major thrust of the research.

3.1.2.5 Resource Processing Pilot Plant (initiation deferred to 1990)

The resource processing pilot plant program will focus on developing the technology for the collection, extraction, and processing of useful materials from extraterrestrial resources. The initial emphasis will be on the production of oxygen, metals, and construction materials on the Moon. Emphasis is on developing and evaluating chemical/physical processes, both analytically and experimentally, for producing these materials. Other technologies requiring advancement are: materials analysis sensors, mechanical separation/extraction, electrochemical separation/extraction, and robotic collection and handling.

3.1.2.6 Optical Communications (initiation deferred to 1990)

The optical communications program will develop the flight-qualified component and system technologies required to demonstrate the transfer of data at mega to gigabit per second rates from LEO to geostationary Earth orbit (GEO), GEO to GEO, and deep space to Earth and/or LEO. Critical technology objectives include the development of lightweight highly efficient laser transmitters, high precision pointing and tracking systems, large aperture lightweight receiver telescopes, and high sensitivity direct and heterodyne detection systems. The components will be engineered and tested in a LEO demonstration. Optical pointing, tracking, and communication performance will be demonstrated by returning data at a 20 megabit per second rate from Mars to either GEO, LEO, or Earth. The latter objective may be accomplished through an experiment package aboard Cassini.

The focus in this program will be on the Shuttle-based Laser Technology Experiment Facility and the Cassini flight experiment package. This research thrust, which builds on OAST's Research and Technology (R&T) base, includes such areas as laser transmitters, sub-microradian accuracy, open and closed loop pointing and tracking systems, direct and heterodyne detection components for receivers, and associated optical components such as mirrors, lenses, and filters.

3.1.3 Humans in Space

3.1.3.1 EVA/Suit

Objectives of the EVA/Suit program are to provide a technology base and a capability for humans to perform extraterrestrial EVA for extended periods. A reliable technology base for a high mobility, serviceable EVA suit, with a compact fully regenerable, portable life support system will be developed. Tools, unique end effectors, lightweight materials, thermal management, environmental countermeasures, and communications technologies will be demonstrated in tandem with these development efforts. This program supports only planetary surface EVA/Suits. There is no specific program targeted at in-space EVA/suits.

3.1.3.2 Human Performance

The human performance program will determine technology requirements for: human factors, artificial gravity, and radiation. Human factors will provide the technology and information base to enhance and maintain the safety and productivity of crews on long-duration missions. The major thrusts included in this area are: (1) crew (organization, selection, training, interpersonal interactions, and communications), (2) environment (habitability and stress), and (3) performance (mission task analysis and human-machine interface).

Artificial gravity research is directed at developing, by the early 1990's, a foundation to support decisions regarding the use of artificial gravity and to follow up with Shuttle-based experiments in the mid-1990's. Areas of research include investigation of behavioral and physiological effects of artificial gravity and assessment of artificial gravity options.

In the area of radiation, related research will develop an understanding of the radiation threat to humans and identify and develop techniques for protecting the crew from unnecessary radiation risk. In particular, it will be important to estimate the radiation doses and assess potential effects from acute and chronic exposure to radiation and to identify and develop technological countermeasures for minimizing radiation-induced damage from galactic cosmic rays and solar particle events.

3.1.3.3 Space Human Factors

The objective of the space human factors program is to enable safe and productive human performance throughout and after long duration space flight and lunar/planetary missions. This program will focus on: (1) human performance models and databases, (2) design tools for addressing man-machine interfaces, (3) crew support systems, (4) human capabilities enhancement techniques for information display and integration, and (5) human-automation-robotic systems.

3.1.3.4 Crew Protective Systems

The crew protective systems program will focus on the research and technology to enable countermeasures against the adverse physiological effects of long-term microgravity and in-space exposure to radiation. More specifically, it will address artificial gravity systems and radiation protection (including vehicle/system design strategies and materials). This program is at a low level of planning maturity.

3.1.3.5 Physical/Chemical Life Support

The physical-chemical life support program will emphasize the development of highly efficient air revitalization, water reclamation, waste treatment, air and water quality, and thermal control technologies. These technologies will be developed and integrated into a total life support system to minimize the requirements for stored consumables and decrease or eliminate the resupply requirements (selected aspects of food management and bioregenerative systems will be developed).

Air revitalization will address oxygen generation, carbon dioxide removal, nitrogen generation, trace and microbial contaminant removal, and water reclamation and solid waste treatment management. Development issues related to the use of materials from local resources, interfaces with portable life support systems, and use of artificial intelligence and expert knowledge systems also will be addressed.

3.1.3.6 Bioregenerative Life Support System

The goal of this program is to identify requirements for exploration mission applications of bioregenerative life support. This goal includes identifying the conditions of advantage over the Physical/Chemical Closed Loop LSS alone, identifying candidate technologies, and identifying the extent different waste streams must be processed for recycling to a plant growth chamber. The Bioregenerative Life Support program will determine the engineering and system performance requirements for biologically-based systems and sub-systems technologies to provide food production and processing, and waste management. This program represents an enhancement to the Controlled Ecological Life Support System (CELSS) program, managed by the OSSA Life Sciences Division.

3.1.4 Space Transfer

3.1.4.1 Chemical Transfer Propulsion

The objective of the chemical transfer propulsion program is to develop space-based, high performance chemical transfer propulsion systems as well as lander propulsion systems to provide high performance over a wide throttle range. A LOx/LH_2 expander cycle engine has been identified as the primary candidate propulsion system that will meet these requirements. Development technologies include high performance variable flow components, high expansion ratio nozzle flow characterization, design for in-space maintainability, and integrated health monitoring/control systems that will provide automated preflight operations as well as fault tolerant engine flight operations. This program will validate high performance expander cycle engine concepts, including high pressure cycle balance demonstrations, component interaction predictions, engine controls, and system level health monitoring.

3.1.4.2 High Energy Aerobraking

The high energy aerobraking program will identify the technology requirements for uses of aerobraking at Earth and Mars with entry velocities up to 14 km/s. This aerobraking program will be conducted in two phases. Phase I will establish mission requirements, develop/improve computational fluid dynamics (CFD) codes, develop/validate fault-tolerant GN&C, and evaluate advanced thermal protection system materials and designs. Flight validation in a "Planetary Return Flight Experiment" will be considered in Phase II and will be coordinated with the CSTI Aeroassist Flight Experiment.

3.1.4.3 Cargo Vehicle Propulsion

The cargo vehicle propulsion program will establish the feasibility of high performance electric propulsion for manned and robotic solar system exploration. The performance objectives of the program are: high specific impulse (over 4000 Isp); high efficiency (over 60%); and acceptable life. The electric propulsion technologies developed must also be scalable to multi-megawatt power levels. Sufficient durability will enable a total impulse on the order of 108 newton-seconds per engine. After development and testing, the most promising thruster (ion or magnetoplasmadynamic) will be selected for further development.

3.2 CSTI Element Programs

The role of CSTI is to produce technologies addressing areas where a broadened technology base is required, and specific user needs exist. CSTI includes three major programs (Transportation, Operations, and Science). Within the three major program areas are ten element programs. The following subsections contain a brief summary of each of these elements.

3.2.1 Transportation

3.2.1.1 Earth-to-Orbit Propulsion

The goal of the Earth-to-Orbit (ETO) Propulsion program is to provide the technology base necessary to proceed with the development of higher performance, longer-life, low life-cycle-cost pump-fed oxygen/hydrogen and oxygen/hydrocarbon rocket engines. Although focused primarily on fully reusable manned vehicles, the resulting design and development tools will be applicable to expendable or partially reusable cargo delivery vehicles.

In order to meet these objectives, the ETO Propulsion program will focus on key rocket engine technology issues such as, performance enhancements, increased component durability, the ability to accurately predict component/engine performance service life, increased quality and reliability, and the development of real-time onboard engine-condition monitoring, safety monitoring, and engine controls aimed at both lower cost and more reliable ground and flight operations. The program is organized around three major rocket engine subsystems: (1) combustion devices, including main thrust chambers and turbine drive gas generators; (2) turbomachinery; and (3) system monitoring and control.

3.2.1.2 Booster Technology

The CSTI Booster Technology program will develop and validate design and analysis tools needed for future development of large scale hybrid and pressure-fed liquid booster propulsion concepts as alternates to solid rocket motors. These alternate booster propulsion concepts will include emergency shut-down capability, thrust throttlability and tailoring, increased performance, lower cost propellant, and the potential for eliminating environmental contamination.

Pressure-fed liquid efforts will address technologies unique to low pressure, high thrust propulsion systems and will augment the ETO propulsion activity that is focused on high chamber pressure, high thrust pump-fed systems. This program will develop and validate analytical models and advanced design concepts through component level and large scale [3337.5 kN (750 klbs) thrust] system level pressure-fed booster testing.

Hybrid technology efforts will develop and validate a data base for low cost hybrid boosters consisting of a pump or pressure-fed liquid oxidizer and rubber-based solid fuel. Analytical tools and advanced hybrid design concepts will be developed and validated through component level and large scale system level testing.

3.2.1.3 Aeroassist Flight Experiment (AFE)

The AFE program will investigate the critical vehicle design technologies and upper atmospheric characteristics applicable to an Aeroassisted Space Transfer Vehicle (ASTV). The aeroassisted maneuver offers a propellant saving that would otherwise be required to perform braking and/or orbital capture engine firings. Because the flight region of the ASTV is unique from other missions and there are no ground test facilities to support simulations, a flight experiment will be required.

AFE will develop a flight database for definition of the environment in which the ASTV will fly and will result in aerothermodynamic/thermodynamic flight-validated CFD codes. The program will also demonstrate GN&C techniques and provide alternate thermal protection system materials to allow development of lightweight, flexible drag-device concepts.

3.2.2 Operations

3.2.2.1 Control of Flexible Structures

The control of flexible structures program will develop structures and controls technology to enable the design, verification, and qualification of precision space structures and large flexible space systems. The objectives of this program include developing control structures interaction (CSI) systems and concepts, integrated analysis and design, ground test methodology, and in-space flight experiments.

3.2.2.2 Autonomous Systems

The autonomous systems program will develop, integrate, and demonstrate artificial intelligence technology research. The program includes five research areas: planning and reasoning, control execution, operator interface, systems architecture and integration, and demonstration (Space Station testbeds and specific domain demonstrations).

3.2.2.3 Robotics

The robotics program will develop the technology base to support the evolution from teleoperations to telerobotics. The program includes five core activities: sensing and perception, planning and reasoning, control execution, operator interface, system architecture and integration, and integration telerobotic testbed.

The program is focused towards a ground-demonstrated integrated laboratory telerobot that combines the immediacy of execution of teleoperation with the efficiency and precision of supervised autonomy. In addition, advanced technologies for the Space Station Flight Telerobotic

Servicer will be developed (system architecture, testbed software and taskboards, force reflecting hand controllers, flight-like manipulator arms and software, and machine vision subsystem).

3.2.2.4 High Capacity Power (HCP)

The HCP program will develop the technology base to support long duration, high capacity power requirements for NASA initiatives, focus on increasing system thermal and electric energy conversion efficiency at least fivefold, and achieving systems compatible with space nuclear reactors. There are six areas of activity: free-piston Stirling power convertor, thermoelectric power converters, thermal management system, power management, system diagnostics, and environmental.

3.2.3 Science

3.2.3.1 Precision Segmented Reflectors

The objectives of the precision segmented reflectors program is to develop the materials, structures, and control technology to enable the design of large, lightweight, high precision orbiting astronomical instruments. Three key areas of activity include: precision segmented reflector integration, panel technology, and precision segmented reflector primary structures and controls.

3.2.3.2 Science Sensor Technology

The science sensor technology program will provide the basis for the development and implementation of scientific sensing instruments for missions investigating the Earth, solar system, and universe. To avoid atmospheric absorption, future instruments will operate from Earth orbit, a fact accounted for in current research. There are four elements to this program: passive non-coherent systems, passive coherent systems, active systems, and cryogenic systems.

3.2.3.3 High Rate/Capacity Data

The objective of the high rate/capacity data program is to develop systems in high speed, high volume data handling for future science missions. This program includes four elements: technology planning and architecture definition, technology development, engineering development modules, and testbed. Technologies being developed include: high rate image processor, synthetic aperture radar (SAR) processor development, general purpose components, and storage technology.

4 Recommendations

The current Pathfinder program does not have the scope or funding level to support the OEXP technology requirements as defined by the FY89 case studies as shown in table 2.4-I. To accomplish exploration missions to the Moon and Mars it will be necessary to significantly increase the scope and funding for the technologies required.

The crosscutting technologies listed in section 2.2 are considered an integral component of the technologies required for the total program to accomplish its goals. While these crosscutting technologies are not specifically listed as areas of separate technology development, their importance cannot be over emphasized. They must be funded at the necessary level and focused to other technology areas.

The ExTWG has been instrumental in the formulation of this document and it is recommended that this group be maintained as an advisory committee to OEXP to support and review the technology programs and progress as the lunar and Mars program matures.

A technology symposium once a year on the technologies that are being used to support the program is recommended to allow the community to present the status, progress, and other information pertinent to OEXP.

There are several technology programs currently supported by Pathfinder and CSTI that must have continued funding in the future. Some of these programs are: SP-100, AFE, and Closed Regenerative Life Support. These technologies will be required to support early phases of human exploration.

Technology development will require the coordination of several Headquarters offices to accomplish an evolutionary exploration program. OEXP must provide mission schedules to allow for the timely development of technology and allow for the development of long lead-time technologies by the technology development offices within NASA.

The magnitude of a lunar or Mars exploration technology development program will necessitate the coordination of most of the NASA Headquarters offices and other research facilities such as DARPA, national laboratories, universities, and industry. It is recommended that a multi-government, academic, and industrial group be established to advise OEXP on the resolution of technology problems.

5 Acknowledgements

Many people have contributed to the process of determining technology needs for human exploration. Certainly all members of the OEXP study team have, in one way or another, made significant contributions. Major contributions have come from the OEXP Integration Agents. The conceptual definition of the various systems required for human exploration form the very basis and foundation for credible identification of technology needs. Similarly, the contributions from the Special Assessment Agents are of particular significance. The SAA's study results yield valuable data to help understand the benefit and feasibility of the various systems and technologies.

Another key ingredient has come from the interaction with and participation of the OAST technology working groups, such as the High Energy Aerobrake Working Group. These interactions have not only yielded more credible systems and concepts in the OEXP case studies, but have been of considerable value in the technology identification process. The OEXP team has a greater awareness of the technology issues and concerns thanks to these working groups.

The recently formed ExTWG has been instrumental in formulating and reviewing this particular assessment. The ExTWG has served a very valuable function of developing an integrated technology assessment that cuts across all IA's and SAA's. In particular, the MASE Technology Agent has been instrumental in the overall integration and synthesis of the exploration technology needs.

Finally, John Mankins, the OAST Pathfinder Program Manager has been of great assistance in the formulation of the identification process, and in determining the data to be documented that will ensure that the results be of benefit to both the OAST and OEXP communities.

Acronyms and Abbreviations

88-CS-1.0	1988 Expedition to Phobos case study
88-CS-2.0	1988 Expedition to Mars case study
88-CS-3.0	1988 Lunar Observatory case study
88-CS-4.0	1988 Lunar Outpost to Early Mars Evolution case study
88-SA-1.1	Lunar SP-100/Stirling Engine Design special assessment
88-SA-1.2	Lunar Observatory Extended Stay Time Power special assessment
89-BT-5	Fuel System Architecture broad trade study
89-CS-2.1	1989 Mars Expedition case study
89-CS-4.1	1989 Lunar Evolution case study
89-CS-5.0	1989 Mars Evolution case study
89-SA-1	Power special assessment
89-SA-1.10	MMW Power Plant special assessment
89-SA-1.11	Low Power Robotic Rover special assessment
89-SA-1.5	Manned High Power Rover special assessment
89-SA-1.7	SP-100 Thermoelectric Lander special assessment
89-SA-2	Propulsion special assessment
89-SA-2.2	In Situ Propellant Utilization special assessment
89-SA-2.3	Advanced Propulsion options study
89-SA-3	A&R Human Performance special assessment
A&R	automation and robotics
A/B	aerobraking
AFE	Aeroassist Flight Experiment
ALARA	as low as reasonably achievable
ALS	advanced launch system
ARC	Ames Research Center
ARS	atmosphere revitalization system
ASTV	Aeroassisted Space Transfer Vehicle
AUTO LANDER	Autonomous Lander
AUTO R&D	Autonomous Rendezvous & Docking
AUTO SYS	Autonomous Systems
B/R REQ	Bioregenerative Life Support Requirements
BOOSTR TECH	Booster Technology
CELSS	controlled ecological life support system
CFD	computational fluid dynamics
CFD	Cryogenic Fluid Depot
CHEM TRANS	Chemical Transfer Propulsion

CM	center of mass
CNTL FLEX STR	Control of Flexible Structures
Code E	Office of Space Science and Applications (OSSA)
Code M	Office of Space Flight (OSF)
Code R	Office of Aeronautics and Space Technology (OAST)
Code S	Office of Space Station (OSS)
Code T	Office of Space Operations (OSO)
Code Z	Office of Exploration (OEXP)
CREW PROT	Crew Protective Systems
CSI	control structures interaction
CSTI	Civil Space Technology Initiative
CTV	cargo transfer vehicle
CV PROP	Cargo Vehicle Propulsion
DARPA	Defense Advanced Research Projects Agency
DATA CAPACITY	High Rate/Capacity Data Systems
dep	departure
DMS	data management system
DoD	Department of Defense
DOE MMW/MMW	Department of Energy - Multi-MegaWatt Power Program
DoE	Department of Energy
DSB	deep space burn
ECCV	Earth crew capture vehicle
ECLSS	environmental control and life support system
ECV	electric cargo vehicle
ELV	expendable launch vehicle
EMU	extravehicular mobility unit
EOC	Earth orbital capture
EOS	Earth observational satellites
ETM	Earth-to-Mars
ETO	Earth-to-orbit
ETO PROP	Earth to Orbit Propulsion
EVA	extravehicular activity
ExTWG	Exploration Technology Working Group
FDIR	fault detection, isolation, and recovery
FY	fiscal year
GCR	galactic cosmic radiation
GEO	geostationary Earth orbit
GN&C	guidance, navigation, and control

GPBS	gigabytes per second
HCP	high capacity power
HEAB	High Energy Aerobraking
HIGH CAP PWR	High Capacity Power
HLLV	heavy lift launch vehicle
HMF	health maintenance facility
HUM PERFORM	Human Performance Requirements
IA	Integration Agent
IMLEO	initial mass to low Earth orbit
IN-SP A&C	In-Space Assembly & Construction
INS	inertial navigation system
IOC	initial operational capability
Isp	specific Impulse
ISPP	in situ propellant production
ISRU	In Situ Resource Utilization
ITV	interplanetary transfer vehicle
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
kWe	kilowatts – electric
kWt	kilowatts – thermal
L/D	lift to drag ratio
LANL	Los Alamos National Laboratory
LaRC	Langley Research Center
LEO	low Earth orbit
LeRC	Lewis Research Center
LLO	low Lunar orbit
LOX	liquid oxygen
LSS	life support system
MASE	Mission Analysis and Systems Engineering
MAV	Mars ascent vehicle
MCSV	Mars crew sortie vehicle
MCV	Mars cargo vehicle
MDV	Mars descent vehicle
MELS	Mars entry and landing system
MLM	Mars landing module
MMIC	monolithic microwave integrated circuit
MMU	manned maneuvering unit

MMW	multi-megawatt
MOC	Mars orbital capture
MPV	Mars piloted vehicle
MRSR	Mars Rover/Sample Return
MSFC	Marshall Space Flight Center
MWe	megawatts – electric
MWt	megawatts – thermal
NASA	National Aeronautics and Space Administration
NEP	nuclear electric propulsion
NERVA	Nuclear Engine for Rocket Vehicle Application
NFP/No Focused Prog	Program not focused to exploration needs
NP/No Program	No Program Exists
NRX	Nuclear Reactor Experiment
NTR	nuclear thermal rocket
OAST	Office of Aeronautics and Space Technology
OEXP	Office of Exploration
OMV	orbital maneuvering vehicle
OPTCL COMM	Optical Communications
OSF	Office of Space Flight
OSO	Office of Space Operations
OSS	Office of Space Station
OSSA	Office of Space Science and Applications
OTA	Office of Technology Assessment
OTV	orbital transfer vehicle
P/C LSS	Physical-Chemical Life Support
PF	Pathfinder
Ph/D	Phobos/Deimos
PHOTONICS	Photonics
PLSS	portable life support system
PREC SEG REFL	Precision Segmented Reflectors
PSS	Planetary Surface System
PTV	personnel transfer vehicle
PVA	photovoltaic array
QF	quality factor
R&D	Research and Development
R&T	Research and Technology
RCS	reaction control system
rem	roentgen-equivalent man

RFC	rechargeable fuel cells
RLSS	regenerable life support system
ROVER	Planetary Rover
rpm	revolutions per minute
RTG	radioisotope thermal generator
RTLT	return trip light time
SAA	Special Assessment Agent
SAAP	sample acquisition, analysis, and preservation
SCNTR	solid core nuclear thermal rocket
SE	Stirling engine
SENSORS	Science Sensor Technology
SP HUM FCTRS	Space Human Factors
SP-100	Space Nuclear Power program
SP-100	100 kWe-class space power system
SPE	solar particle event
SR	sample return
SRD	Studies Requirement Document
SSF	Space Station Freedom
SSME	Space Shuttle Main Engine
STS	space transportation system
STV	space transfer vehicle
SURF POWER	Surface Power
SV	sievert (1.0 SV = 100 rem)
T/W	thrust to weight ratio
TBD	to be determined
TEI	trans-Earth injection
TMI	trans-Mars injection
TNDB	Technology Needs Database
TPS	thermal protection system
TVS	thermodynamic vent system
VCS	vapor cooled shield
VHSIC	very high speed integrated circuit
VLBI	very long baseline interferometry
WC-SPE	worst credible solar particle event
WMS	waste management system

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16. Abstract

The Office of Exploration (OEXP) at NASA Headquarters has been tasked with defining and recommending alternatives for an early 1990's national decision on a focused program of human exploration of the solar system. The Mission Analysis and System Engineering (MASE) group, which is managed by the Exploration Studies Office at the Lyndon B. Johnson Space Center, is responsible for coordinating the technical studies necessary for accomplishing such a task. This technical report, produced by the MASE, describes the process that has been developed in a "case study" approach. The three case studies that were developed in FY 1989 include:
1. Lunar Evolution Case Study, 2. Mars Evolution Case Study, 3. Mars Expedition Case Study. The final outcome of this effort is a set of programmatic and technical conclusions and recommendations for the following year's work.

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Automation & Robotics
Nuclear power & Propulsion
Advanced Life Support
Martian Moons
Telecommunications, Navigation and Information Management
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Mars Transfer
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